Synchronous Generator-based Grid-interface Converter for Energy Storage Systems Integration

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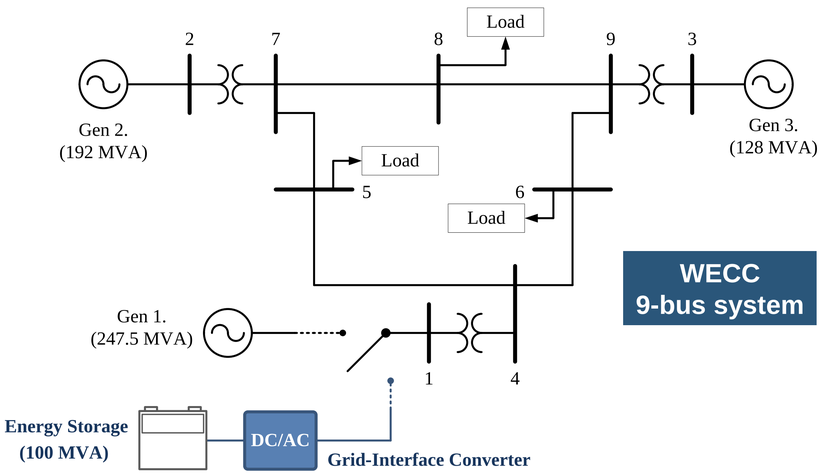


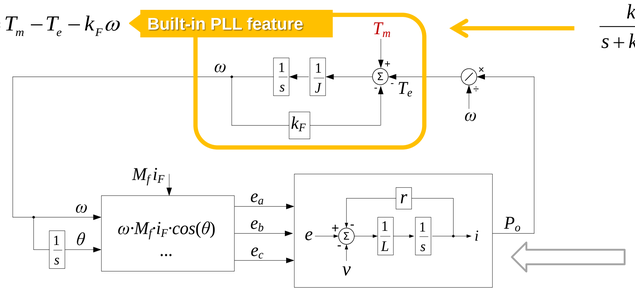
WECC 9-bus system

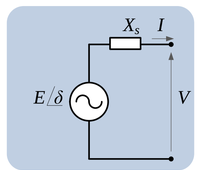
Synchronous Generator Model

$$J\frac{d\omega}{dt} = T_m - T_e - k_F\omega$$

Built-in PLL feature

$$\frac{k_J}{s + k_F k_J}$$

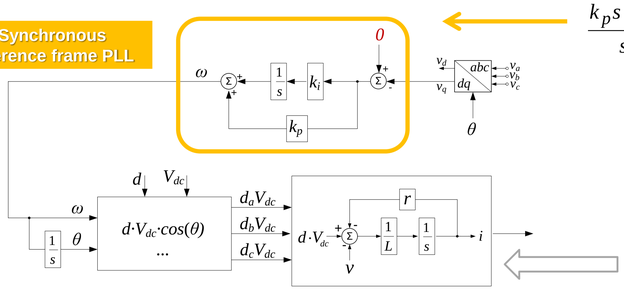


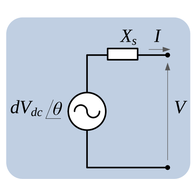


Power Converter Model

Synchronous reference frame PLL

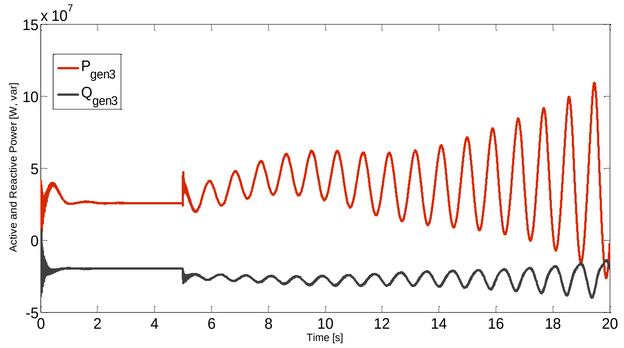
$$\frac{k_p s + k_i}{s}$$

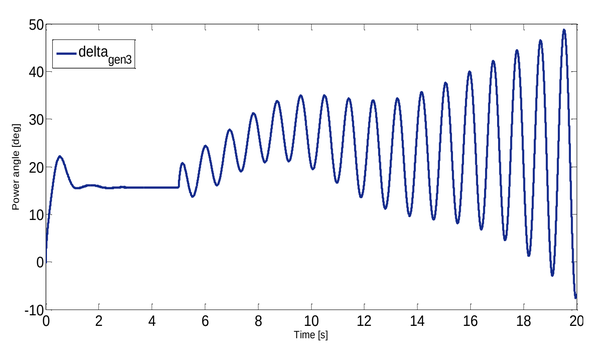




Loss of Generation Case Study (Generator 2 off @ 5s)

$$P_{Load}^{Total} (\approx 180\,\text{MW}) < P_{Gen1} + P_{Gen3}$$

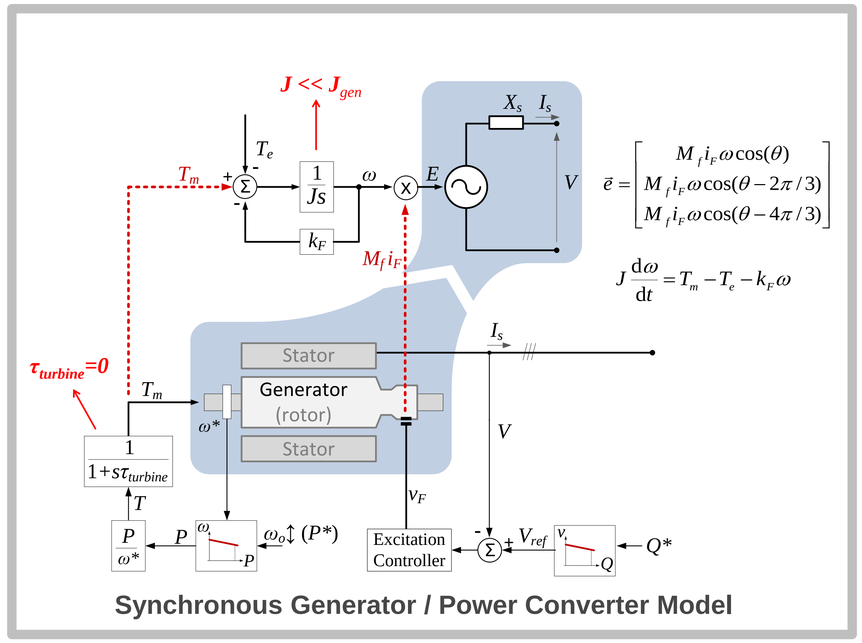




Evident system instability caused by the loss of Generator 2.

Although total power of the sources was higher than the total system load in that case, power delivery was delayed due to large time constants of the governors.

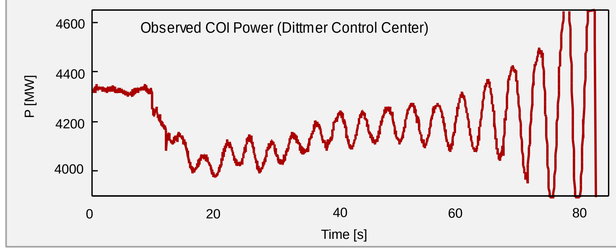
Power Electronics Converters can be modeled as Synchronous Generators with governor delay set to 0, and moment of inertia significantly lower than in synchronous generators:



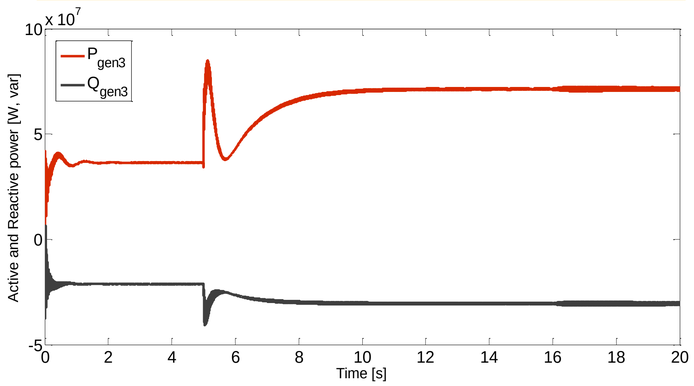
Synchronous Generator / Power Converter Model

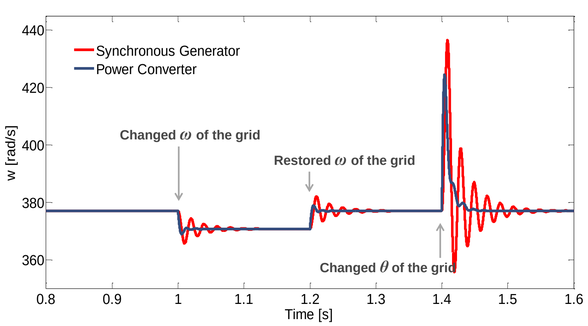
A Real System Dynamics (Blackout)

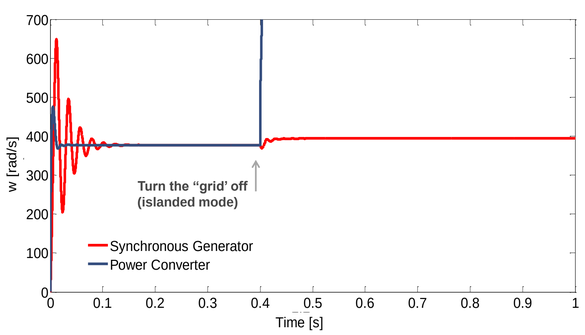
Recorded system dynamics of a real power flow during the August 10, 1996 event (California and Oregon Intertie).

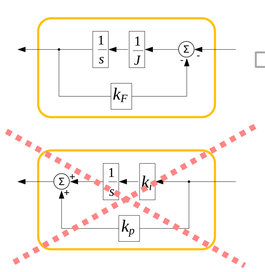


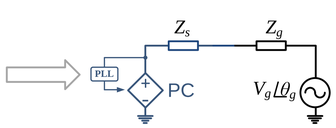
When Grid-interface Converter with Energy Storage was connected at the bus No. 1, the system instability did not happen, due to a fast power delivery:











Although dynamically slower, power converter's PLL is now stable when transitioning from/to grid-connected to/from islanded state!